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General Information for OSPOR

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Review

Johann August Miertsching and his circum-continental Travel as Inuit Language Interpreter on Board H.M.S. *Investigator*

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Abstract

Johann August Miertsching (1817-1875) was translator of the Inuit language at H.M.S. *Investigator* in a polar Expedition in search of the lost Sir John Franklin Expedition. Miertsching's voyage took 4 years and 8 months, overwintering three consecutive years in the polar seas and as such being part of the first circum-American continental travel. Monthly mean temperature and atmospheric pressure data on board of the *Investigator* are among the early meteorological observations in the Polar Region.

Key words: Miertsching, interpreter, Inuit, *Investigator*, John Franklin, polar expedition, Capt. Mac Clure

1. Introduction

On May 19, 1845, Captain Sir John Franklin[1] left England on board of the H.M.S. *Erebus* and H.M.S. *Terror* trying to determine the North-West Passage, exploring the Canadian Arctic and recording magnetic observations that could help navigation in polar areas. They wintered 1845-1846 and 1846-1847 being trapped in ice; the ships were abandoned in April 1848 and the survivors tried to reach Canadian mainland but disappeared. Jane, Lady Franklin, pushed the Admiralty to launch Arctic expeditions to search for Franklin's lost expedition. An expedition was launched in 1850, by Captain Richard Collinson, H.M.S. *Enterprise*, and Commander Mac Clure, HMS *Investigator*, in this context of the search.

Johann August Miertsching, a Moravian Brethren missionary in Labrador, was aboard the *Investigator* as translator of the Inuit language. As a matter of fact, the *Investigator* had to be abandoned itself after overwintering 3 consecutive years in the Arctic, and the crew was saved by a sledge-party to the *Resolute* and the *Intrepid*, Capt. Kellett at Dealy Island, near the south coast of Melville Island. Later on, they went in sledge parties to the *North Star*, at Beechey Island, becoming in this way the first circum-continental travelers.

2. Johann August Miertsching: a life picture

Johann August Miertsching (in Upper Sorbian language[2] *Jan Awgust Měrćink)* was born on 21 August 1817 in Gröditz, near Weißenberg, Saxony, Germany. Miertsching's father, Johann Miertsching, was a cottager working as a carpenter; he died when Johann August was only 2 ½ years old. Johann August Miertsching learned the shoemaker's trade at the school of the Moravian Brethren in Kleinwelka[3] near Bautzen. He was admitted to the Moravian Brethren Community on March 25, 1841, and took over the master's office in the shoemaking school in Kleinwelka in May 1841. In the autumn of 1843, the Unity Elders Conference – in German: Unitäts-Ältesten-Conferenz (UAC) – decided to send three single Brethren to Labrador and J.A. Miertsching was one of them; in February 1844 he was designated by the decision of the lot. He travelled from Kleinwelka to London, arriving there on June 3, 1844.[4] The missionaries destined for Labrador were present at the half-yearly meeting of the Society of the Furtherance of the Gospel (SFG) on the next day;[5] they departed on the mission ship *Harmony III* in the morning of June 11, 1844.

Brother Miertsching reached his destination, the missionary station Okak [Okkak], on August 11, 1844.[6] Among the presents of mission friends brought by the

[1] Sir John Franklin (1786-1847), a British Royal Navy officer, explorer and colonial administrator.
[2] Upper Sorbian language: also named Wendish, a minority language belonging to the West Slavic branch, spoken by the Sorbs in Upper Lusatia, Saxony, Germany.
[3] Kleinwelka: a subdivision of the city of Bautzen, in eastern Saxony, site of a settlement of the Moravian missionaries; for many years it was the seat of a boarding school for the children of Moravian missionaries from all over the world.
[4] Periodical Accounts, Vol. XVII, p. 47-48; Journal de l'Unité des Frères, 9[e] année, 1844, p. 292.
[5] Periodical Accounts, Vol. XVII, 1844/1846, p. 46-47.
[6] Nachrichten aus der Brüder-Gemeine, 30[ster] Jahrgang, 1848, p. 406.

Harmony was a new organ which was technically installed and musically tuned by Miertsching and which was much appreciated by the Inuit.[7] Miertsching had to endure extreme winter temperatures like in the winter 1844-1845, 'the thermometer often fell to 36 degrees under zero of Fahrenheit' [-37,8° C]. [8] Miertsching undertook his first travel by dog sled in April 1846 as Br. Glitsch 'was seriously ill at the mission station Hebron and wanted the medical aid of Br. Herzberg'. As Herzberg 'was not being able to travel alone on account of his delicate state of health, Miertsching was appointed to accompany him'. During the journey, 'the cold was intense (45 degrees Fahrenheit below freezing point' [-42,8° C]).[9]

A letter by Br. Gregor of the UAC to Lundberg, Superintendent of the Labrador mission, includes the instruction to send one of the single Brethren to Germany in order to get married. Ultimately, the designation of Miertsching was most probably based upon his more liberal and solidarity views on the missionary activity with the Inuit in Labrador. The *Harmony* 'took her departure from Okak September 19, 1849, and after a somewhat tedious and boisterous passage, casting anchor at Horselydown[10] on the 23rd of October';[11] from there Miertsching travelled by ferry to Rotterdam and train to Magdeburg, finally reaching Kleinwelka on November 24, 1849 (M. & W. Opel, 2022, p. 125).

Fig. 1 Portrait of J.A. Miertsching (1817-1875) (Collection Jannasch, M. & W. Opel, 2022).

In the years 1850-1854, Miertsching took part in the expedition as translator of Inuktitut in the *Enterprise*, Capt. Collinson, and the *Investigator*, Commander Mac Clure, Arctic Expedition searching for the lost expedition of Sir John Franklin (see chapter 3).

On Saturday October 7, 1854, at 8 o'clock in the evening, when it was already completely dark, the North Star anchored in the naval harbor of Sheerness, Miertsching 'having been absent four years, eight months, and eighteen days'.[12] This is the end of the polar expedition of Collinson and McClure searching for Sir John Franklin. In this regard, the expedition was unsuccessful, but the first circum-continental voyage was carried out and large areas in the Canadian polar areas were discovered by ship and by extensive man-carried sledge travels over land and sea ice. Figure 1 shows a daguerreotype of Miertsching taken in London.

Finally, in November 1854, Miertsching arrived at home in Gröditz and met his family. The UAC in Berthelsdorf, near Herrnhut, Saxony, decided not to send Miertsching again to Labrador and he 'received a call to the service of the Mission in South Africa' mid 1856. Johann August Miertsching married Sister Clementine Auguste Erxleben on October 7, 1856, and, already on the 20th they sailed from Altona, heading for the Cape of Good Hope, in the ship *San Francisco*'[13]; they reached their destination on Sylvester 1856.

Miertsching's first task as a missionary in South-Africa was doing the trade and keeping the shop in Elim.[14] In 1861, the family was sent to the Moravian mission settlement Gnadenthal. They left South Africa in April 1869[15] and settled at Kleinwelka, Saxony, where Clementine died on December 21, 1869, and Johann August Miertsching on March 30, 1875.[16]

3. The narrative of Miertsching's circum-continental journey

John Richardson [17] strongly suggested the appointment of a missionary of the Moravian Brethren to accompany Capt. Collinson's Arctic Expedition as interpreter of the Esquimaux language. The person selected would be capable to have friendly interactions with the Inuit and possibly might obtain from them relevant information on the lost John Franklin expedition

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[7] Nachrichten aus der Brüder-Gemeine, 30ster Jahrgang, No. 1, Januar 1849, p. 8-10; Nachrichten aus der Brüder-Gemeine, 30ster Jahrgang, 1848, p. 407.

[8] Periodical Accounts, Vol. XVII, 1844/1846, p. 313.

[9] Periodical Accounts, Vol. XVIII, 1844/1846, p. 80-81.

[10] Horselydown / Horsleydown, a location on the southern bank of the Thames, by the 19th century an area crowded with business of all kinds.

[11] Periodical Accounts, Vol. XIX, p. 215-216; Journal de l'Unité des Frères, 15e année, 1850, p. 31-32.

[12] Periodical Accounts, Vol. XXI, 1853/1856, p. 267.

[13] Periodical Accounts, Vol. XXII, 1856/1858, p. 143-144; Missions-Blatt aus der Brüdergemeine, N° 10, October 1856, p. 186; Missions-Blatt aus der Brüdergemeine, N° 12, December 1856, p. 225.

[14] Elim is a village on the Agulhas Plain in the Western Cape of South Africa. It was established in 1824 by German missionaries as a Moravian Brethren mission station.

[15] Periodical Accounts, Vol. XXVII, 1868/1871, p. 208.

[16] Periodical Accounts, Vol. XXIX, 1873/1876, p. 360.

[17] John Richardson (1787-1865), a Scottish naval surgeon, naturalist and Arctic explorer.

(The Athenaeum, 1850, p. 310). It was not until December 22, 1849, that the Admiralty commissioned Edward Parry[18] to enter negotiations with Peter Latrobe, secretary of the Moravian Mission Society in London,[19] to look for an Inuktitut translator among the Greenland or Labrador missionaries to accompany the Collinson-Mac Clure Expedition (Brandes, 1854, p. 92). The UAC at Berthelsdorf discussed the subject. J.A. Miertsching, although initially reserved, accepted the decision of the lot of January 5, 1850, and departed immediately to London[20] where he arrived in all haste on January 16. Baillie-Hamilton[21] wrote to Capt. Collinson on January 17: '*I am commanded by the Lords Commissioners of the Admiralty to acquaint you that they consider Mr. Miertsching (the Eskimo interpreter) as placed under your special protection; that Mr. Miertsching is to mess at the gun-room table; and you are from time to time, as you may deem necessary to supply any reasonable sums for this gentlemen's mess, or other necessary expenses.*' (Brandes, 1854, p. 93) Highly respectable for the shoemaker!

Miertsching traveled from London, to Devonport, Plymouth. A boat was rented which brought them to the *Investigator* in Plymouth Sound where he met Captain Collinson, *Enterprise*, and Commodore Mac Clure, *Investigator*. Since there was no cabin free on the *Enterprise,* he got his cabin on the *Investigator*, but it was planned that he would be transferred to the *Enterprise* in Valparaíso (Opel, M. & W., 2022, p. 133). On Sunday, January 20, 1850, at 6 h in the morning, the anchor was lifted in good winds and the long lasting journey started.

Mid-April 1850, the *Gorgon* towed both Arctic Expedition ships through the Magellan Strait to the Pacific Ocean where they set sail for the Sandwich Islands (Hawaii). When Capt. Mac Clure arrived off Honolulu on 1 July, he found that the *Enterprise* had gone on at once ahead of him, fearful of losing the short remains of the summer. Mac Clure decided to stay only 4 days at Oahu and sailed straight lines north to The Bering Strait that he reached without problems on July, 27. Meanwhile Collinson sailed the conventional but longer way. The *Enterprise* and the *Investigator* had finally parted ways in the expedition - they would never meet again. On July 29, the *Plover*, Capt. Moore[22], was met and on July 31, also the *Herald*, Capt. Kellett.[23] On this occasion, Miertsching informed the Moravian Brethren by letter, dated July 30th, from Cape Lisburne, which was published in missionary journals.[24] Finally, having missed the rendezvous with Capt. Collinson and without any information on the *Enterprise*, Mac Clure decided, on his own responsibility, to enter the Polar Sea in contrast to Kellett's point of view. Figure 2 shows the map of the Arctic Archipelago and northern Alaska and Canada while Fig. 3 shows the track of the *Investigator* from England in January 1850 to the Prince of Wales Strait in September 1850, the place of its first overwintering.

August 1850, Capt. Mac Clure interacted with Capt. Kellett, of the *Herald*, in Behring's Straits, and sent letters to Europe by him. On August 7, the *Investigator* sailed around Point Barrow, and was now east of this headland, at a location no ship had ever reached before, and, on August the 8th, the crew met with some Esquimaux on the Colville River. "On the 20th, we reached the Mackenzie River, and, passing Cape Bathurst, we arrived in Franklin's Bay on September the 1st, 1850." As often as circumstances permitted, Miertsching went ashore and conversed with the Esquimaux, whose language he found to be the very same as that spoken on the coast of Labrador. "From Cape Parry, in Franklin's Bay, we sailed towards the North, surrounded by heavy masses of ice, and discovered land on the 7th of September, to which the name of *Baring's Island* was given. Passing through a channel of moderate with, named *Prince of Wales' Strait*, between *Baring Island* and *Prince Albert's Land* to the eastward, our ship was frozen in, on September 24th, 1850, at lat. 72° 47' N, and 118° 12' W. On October 10, 1850, the British flag was hoisted on the newly discovered land which was named *Prince Albert's Land*." (Miertsching, 1855, p. 56)

Capt. Mac Clure went with a sledge-party to Point Russell, the extreme point of Baring Island, from which, on October 26th, 1850, he saw the entrance into Parry's Sound and Barrow Strait, thus discovering the long

[18] William Edward Parry (1790-1855), a Royal Navy officer and explorer known for his 1819–1820 expedition through the Parry Channel.

[19] Berigten uit de Heiden-Wereld, 1850, p. 61-63.

[20] Journal de l'Unité des Frères, 1850, p. 127-128; Journal de l'Unité des Frères, 1851, p. 85-86.

[21] William Alexander Baillie-Hamilton (1803-1881), a Scottish naval commander, Second Secretary to the Admiralty, serving on the Arctic Council when it was searching for Sir John Franklin.

[22] Thomas Edward Laws Moore (circa 1820-1872), a Royal Navy officer and explorer. From 1847 to 1852, he commanded HMS *Plover*, which was searching for Franklin's lost expedition.

[23] Henry Kellett (1806-1875), a Royal Navy officer, oceanographer and arctic explorer. Kellett commanded the *Herald* in the Arctic in search of the lost Franklin expedition (Dictionary of Canadian Biography).

[24] Periodical Accounts, Vol. XX, 1851/1853, p. 168-169; Nachrichten aus der Brüder-Gemeine, 33ster Jahrgang, Fünftes Heft, 1851, p. 713; Missions-Blatt aus der Brüdergemeine, Funfzehnter Jahrgang, 1851, No. 3, p. 56-60; Journal de l'Unité des Frères, 17e année, février 1852, p. 53-54; Berigten uit de Heiden-Wereld, 1851, No. 8, p. 122.

sought North-West Passage. As the entrance into Parry Sound continued to be blocked up by ice, the *Investigator* sailed south in the summer of 1851, sailing around Baring Island. In April 1851, three sledge parties were sent out, the first one to Wollaston Land in the south; the second to Banks Land in the north-west and the third in the direction of Cape Walker, in the north-east. Miertsching accompanied Mac Clure to Wollaston where many Inuit were found. On September 24th, 1851, the *Investigator* was frozen in on the north side of Baring Island, in the Bay of Mercy, in lat. 74° 6' N., long. 117° 54' W. On April 11, 1852, Capt. Mac Clure and a sledge party reached Winter Harbour on Melville Island, where Capt. Edward Parry overwintered in 1820. He left a message under a pile of stones and arrived back on the *Investigator* on May 9th. As the ice didn't break up in the summer of 1852, they were under the painful necessity of a second wintering on the same spot. The conditions on the *Investigator* became more and more precarious and the daily allowance was only two-thirds of the usual rations, having weakened many members of the crew. As the provisions would not last until November 1853, Mac Clure decided to send two sledge parties, one to Port Leopold, another one, including Miertsching, to the Mackenzie River. In all probability, these parties would follow the fate of the lost Franklin expedition. The departure day was fixed on April 15, 1853, but fortunately, on April 10th, a party led by Lieutenant Pim[25] from the *Resolute*, Capt. Kellett, brought the good news that two ships were waiting to receive them at Dealy Island, near Melville Island.[26] The rescue had been induced by the fact that the party directed by Lieutenant Mecham of the *Resolute* had found the hand written message from the *Investigator* and that Capt. Kellett sent a sledge party in March 1853 to find the *Investigator*. On June 17th, 1853, the full crew of the Investigator had moved to the *Resolute* and Capt. Mac Clure had abandoned the *Investigator.*[27]

In August 1853, Capt. Kellett's ships got loose from the ice, drifted among the ice field but became again stationary on November 13th, at lat. 74° 41' N, long. 101° 22' W, remaining there till April 1854, when Sir Edward Belcher, wintering in Wellington Channel, ordered to abandon the two ships. Mac Clure and the remaining crew of the *Investigator*, among them Miertsching, started on April 14th a sledge-party, over a distance of nearly two hundred miles across the ice to Beechey Island, where they were received on board the *North Star* on April 28th. In this vessel, J. A. Miertsching and the remaining crew of the *Investigator* sailed for England on August 27th, and landed at Sheerness, October 8th, 1854, having been absent four years, eight months, and eighteen days.[28]

Fig. 2 Map of the Arctic Archipelago, according to the latest discoveries of the Franklin Expeditions. Edited and drawn by H. Lange (Brandes, 1854).

Fig. 3 Track of the voyage of the *Investigator* from England in January 1850 till September 1850, the place its wintering (1850-1851) in the Prince of Wales Strait.

4. The genesis of the narrative

Besides Miertsching being present at the meeting of the Society of the Furtherance of the Gospel at the Brethren's Chapel in Fetter-Lane on November 6, 1854, where he was heartily welcomed and where he referenced to the circumstances of his long and perilous journey to the Arctic expedition, he received invitations to give lectures about his polar experiences in many of the Brethren's settlements; he even traveled to Fulneck

25 Bedford Clapperton Trevelyan Pim (1826-1886), a Royal Navy officer, Arctic explorer and author.

26 Letter of Miertsching dated Dealy Island, May 4th, 1853, brought to England by Lieut. Cresswell on Oct. 11th, 1853: Journal de l'Unité des Frères, 19e année, 1854, p. 90; Periodical Accounts, Vol. XXI, 1853/1856, p. 47-48; Berigten uit de Heiden-Wereld, 1853, No. 8, p. 140-146.

27 The sunken wreck of the *H.M.S. Investigator* was discovered by a team of *Parks Canada* scientists in July 2010.

28 Periodical Accounts, Vol. XXI, 1853/1856, p. 48-49; Missions-Blatt aus der Brüdergemeine vom Jahre 1853, N° 9, September 1853, p. 205-212; Das Calwer Missionsblatt, 1854, Nro. 21 und 23, p. 103.

in Yorkshire in company of William Mallalieu, treasurer of the Moravian Mission Society in London. While he was in London, Miertsching talked to Daniel Benham, an author associated with the Moravian Brethren, and at the end of November 1854, a '*Sketch of Life of Jan August Miertsching*' was published (Benham, 1854). Miertsching published a letter, dated November 3, 1854, on the North Pole expedition in *Das Calwer Missionsblatt (*Miertsching, 1855a).

In the spring of 1855, Miertsching worked at Gröditz on the travel report and presented his voluminous manuscript to the UAC. The UAC requested Ottomar Gemusens, editor of the *Nachrichten aus der Brüdergemeine*, to edit the manuscript version. [29] However, the *Reise-Tagebuch* edition shows quite a few differences to the existing handwritten manuscript (M. & W. Opel, 2022, p. 362). A first edition of the travel diary of Miertsching was published in the autumn of 1855 at Gnadau, [30] the second edition (1856) comprises an addition about the Inuit (Miertsching, 1855b).

The interaction that Miertsching had with the Inuit tribes during his polar travel was seen as a 'desire that a Mission should be commenced in high northern latitudes, could not, at least for the present, acceded to on account of the evident possibility of maintaining communication with those regions'.[31]

5. The meteorological observations on board of the *Investigator*

Miertsching's *Reise-Tagebuch* mentions the following meteorological and geographical instructions: "The daily temperature observations are expressed in degrees Fahrenheit (°F) and are usually an average temperature over 24 hours. The latitude and longitude (westerly of Greenwich), in degrees and minutes, were observed at noon 12 hours." The *Reise-Tagebuch* contains also maximum, minimum and medium monthly temperatures. These are most probably copied from Capt. Mac Clure's ship log which Miertsching was allowed to consult as he had to leave his notes behind when the *Investigator* was abandoned (Miertsching, 1855, p. 1).

Figures 4 and 5 represent respectively daily mean temperature from 23 January to 27 July 1850 and from 27 July till 7 October 1850. The first period corresponds from the departure from Plymouth, England, of the *Investigator* until its passage of the Saint Lawrence Island, Alaska, U.S.A. (Fig. 4). This period comprises the travel of the *Investigator* through the Atlantic Ocean, the passage through the Magellan Straits and its travel in the Pacific Ocean, a brief stop at Honolulu, Hawaii, and continuing till Behring's Straits.

Figure 5 shows the decrease in temperature in function of the day of the year. On October 7th, 1850, the *Investigator* was frozen in the ice at latitude 72° 46' N and longitude 118° 12' W.

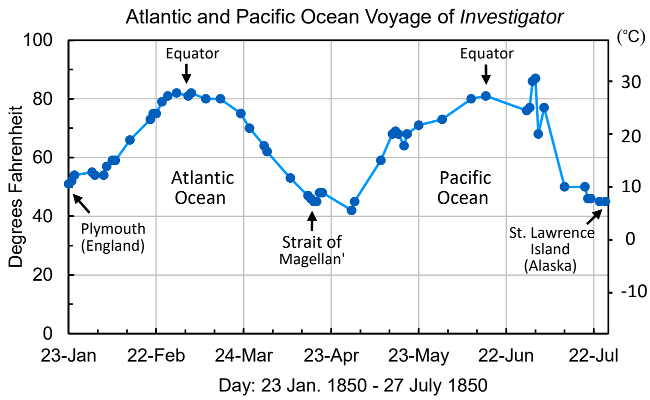

Fig. 4 Daily mean temperature in °F (on the left) and in °C (on the right) on board of the *Investigator* from 23 January till 27 July 1850.

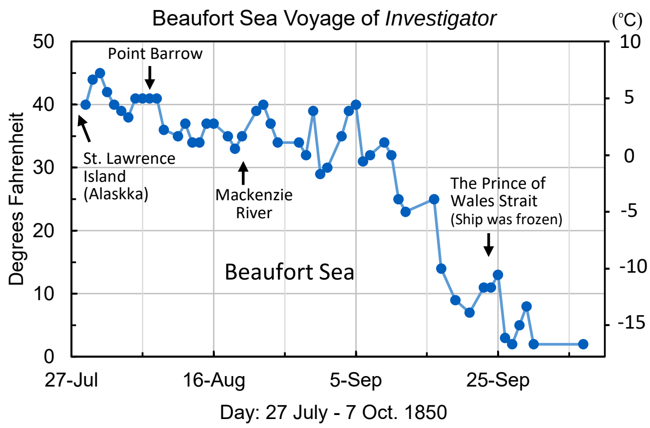

Fig. 5 Daily mean temperature in °F (on the left) and in °C (on the right) on board of the *Investigator* from 27 July till 7 October 1850.

Alexander Armstrong, Surgeon at the *Investigator*, published an *Abstract of Meteorological Journal kept on board H.M.S. Investigator, from January 1850 to March 1853*. The abstract comprises maximum, minimum and monthly mean values of the marine barometer, the aneroid barometer, the sympiesometer[32], the temperature

[29] Missions-Blatt aus der Brüdergemeine vom Jahre 1855, Neunzehnter Jahrgang, N° 9, September 1855, p. 148.
[30] Nachrichten aus der Brüder-Gemeine, 37ster Jahrgang, Sechstes Heft, 1855, Gnadau, p. 982; Missions-Blatt aus der Brüdergemeine vom Jahre 1855, Neunzehnter Jahrgang, N° 12, December 1855, p. 219.
[31] Periodical Accounts, Vol. XXII, 1856/1858, p. 366; Missions-Blatt aus der Brüdergemeine, N° 12, December 1853, p. 213-230; Jahresbericht von dem Missionswerk der evangelischen Brüder-Gemeine, 1854, p. 5-7; Journal des Missions évangéliques, 1855, p. 424; Berigten uit de Heiden-Wereld, 1854, p. 7-25.
[32] A sympiesometer is a compact and lightweight type of barometer that was widely used on ships in the 19th century.

of the air, the temperature of sea-water, the mean force of wind and the prevailing winds (Armstrong, 1857, Appendix). Figure 6 shows the maximum, minimum and monthly mean temperature at the *Investigator* from January 1850 (England) till March 1853 (Bay of Mercy, Baring Island). Figure 7 shows the maximum, minimum and monthly mean atmospheric pressure from February 1850 till March 1853 on board of the *Investigator*. As mentioned above, the data in Fig. 6 and 7 of the first 7 months correspond to the journey from England to Saint Lawrence Island, Alaska, U.S.A.

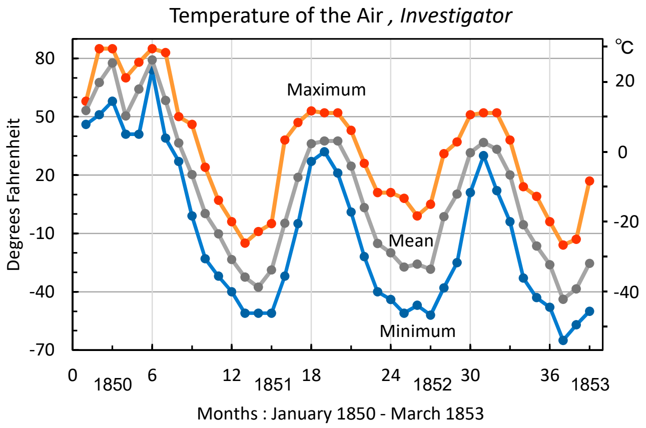

Fig. 6 Maximum, minimum and monthly mean temperature of the air in °F (on the left) and in °C (on the right), observed at the *Investigator*, from January 1850 till March 1853.

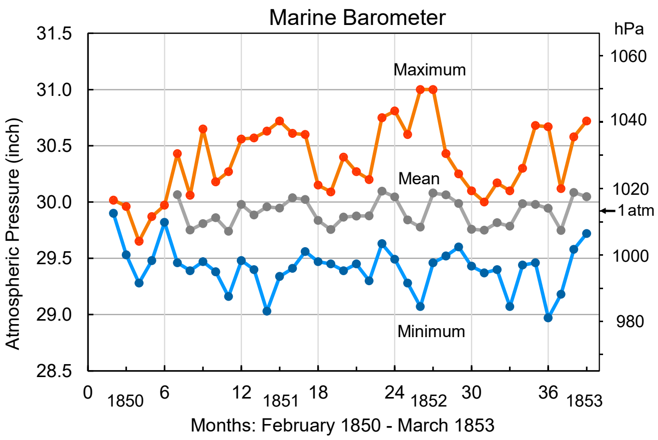

Fig. 7 Maximum, minimum and monthly mean atmospheric pressure, in inches (on the left) and in hPa (on the right), at the *Investigator* from February 1850 till March 1853.

6. Conclusion

J.A. Miertsching, translator, was able to interact with Inuit during the Arctic Expedition of the *Investigator* using the Labrador Inuit language.

Capt. Mac Clure discovered the North-West Passage on October 26, 1850. '*Here I stood on Melville Island*', Miertsching wrote, '*that I am the only Sorbian in these polar regions and that I am taking part in the North-West Passage that we have now discovered and has been looking for more than 300 years.*' (Miertsching's manuscript version, not in the published *Reise-Tagebuch,* on Sunday, 23 April 1853 – see M. & W. Opel, 2022, p. 295).

The *Investigator* was unsuccessful in the search for the lost Sir John Franklin Expedition.

The European missionary journals provide a good overview of Miertsching's travel to the Arctic. Their material is based upon a couple of Miertsching's personal letters, information from official sources such as the Admiralty, English newspapers like *The Times*, Miertsching's presentations after his return from the Arctic, and finally his *Reise-Tagebuch;* all of the information being strongly embedded in the deep religious belief of the Moravian Brethren.

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Summary in Japanese

和文要約

イヌイット語通訳者としてインベスティゲーター号に乗船したヨハン・アウグスト・ミールチングのアメリカ大陸周回旅行

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ヨハン・アウグスト・ミールチング（1817-1875）は、行方不明となったジョン・フランクリン北西航路遠征隊（1845 年出港）の捜索のための H.M.S.インベスティゲーター号に，イヌイット語通訳として乗船した。ミールチングの航海は，1850 年にイギリスを出港し，米大陸南端を回って太平洋からベーリング海峡を通過して北西航路西側のボーフォート海に入り，3 度の越冬を経て 4 年 8 ヶ月に渡った。3 度目の越冬後，船は放棄され，東から来たレゾリュート号に助けられ，最後は陸地を徒歩で横断したが，彼らは初のアメリカ大陸を周回した隊となった。インベスティゲーター号による月平均気温と気圧のデータは、極地における気象観測の最も古い記録の一つである。

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Article

Detection of extremely weak precipitation in Rikubetsu, inland Hokkaido, Japan

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Abstract

Due to the low temperature of the polar atmosphere, the amount of water vapor contained therein is low, and correspondingly, precipitation intensity is relatively weak. For example, in the interior of Antarctica, clear-sky precipitation accounts for half of the annual precipitation, and its contribution to the mass input of the Antarctic ice sheet is considered significant. However, no established method exists for continuously measuring such extremely weak precipitation in polar regions. This study examined how ceilometers, disdrometers, and precipitation weighing instruments can be applied to the detection of weak precipitation in Rikubetsu (43.5°N, 143.8°E), inland Hokkaido. The findings showed that the disdrometer and the ceilometer detected weak precipitation even when precipitation-weighing instruments did not. This precipitation was classified as extremely weak precipitation Type-I (EWP-I) when it had a relatively high precipitation intensity, and as Type-II (EWP-II) when it had a lower intensity. EWP-II was detected by the disdrometer, which detects precipitation particles, and by the ceilometer, which measures backscatter intensity. During EWP-II events, actual precipitation particles were discernable and could be photographed. EWP-II events are observed mainly under ice-saturated conditions at night, when there is an increase in relative humidity due to the decrease in surface air temperature associated with radiative cooling. The ceilometer observed increases in backscatter relatively soon after the temperature drop began after daytime maxima were recorded. Since the disdrometer cannot detect particles smaller than 125 μm, the ceilometer might be better suited to capturing the effects of smaller particles. Weaker precipitation detected only by the ceilometer was classified as extremely weak precipitation of Type-III (EWP-III). The detection of EWP-II and EWP-III demonstrates the potential for recording the occurrence of extremely weak precipitation, including clear-sky precipitation, in polar regions.

Key words: snowfall, precipitation, ceilometer, disdrometer, weighing gauge, Double Fence Intercomparison Reference (DFIR), Rikubetsu

1. Introduction

In polar and cold regions, the total precipitation is lower, and precipitation intensity is weaker compared to other regions, reflecting the low temperatures in these regions. For example, precipitation over the Antarctic region ranges from a few tens of millimeters a day in coastal area to a few millimeters per day inland, even during relatively heavy precipitation events associated with synoptic-scale disturbances (e.g., Konishi et al., 1998, Schlosser et al., 2010).

Even today, accurately measuring snowfall is challenging. The World Meteorological Organization (WMO), along with national weather agencies, researchers, and engineers, are engaged in various experiments and observations to address this issue. Recently, the WMO conducted an international project titled "Solid Precipitation Intercomparison Experiment (SPICE)" during the winters of 2013–2016 (e.g., Nitu *et al.*, 2018, Qiu, 2012). This was the third attempt of its kind, following similar projects in the past. We participated in the most recent SPICE project using data collected at our observation site in Rikubetsu, northern Japan (Hirasawa *et al.*, 2018).

Snowfall outside polar and extremely cold regions is relatively heavy and intense. For such snowfall, the main concerns for accurate measurements are improving the capture rate of precipitation particles and minimizing evaporation losses after collection. These were the central issues addressed during SPICE. In contrast, polar precipitation is characterized by a higher proportion of extremely weak-intensity precipitation events, reflecting the extremely low temperatures in other regions. This adds the additional challenge of measuring precipitation at such low intensities, in addition to the problems associated with accurately measuring capture rate and evaporation. For example, if daily precipitation of 1 mm occurs over 24 hours of continuous precipitation, the precipitation intensity would be 0.04 mm/hr. According to Hirasawa *et al.* (2018), this value is comparable to the resolution of Geonor T200B, one of the standard weighing gauges.

In Antarctica, relatively large precipitation events associated with synoptic-scale disturbances occur only a few times per year, with a maximum frequency of about 10 times annually (Schlosser et al., 2010, Turner et al., 2019). Another major precipitation system in Antarctica is clear-sky precipitation, commonly referred to as diamond dust. Clear-sky precipitation has been recognized as a significant contributor to mass input for the Antarctic ice sheet, not based on quantitative measurements, but because it occurs up to 80% of the year in the interior region (e.g., King and Turner, 1997). Annual precipitation at the coastal Syowa Station is approximately 200 mm (Konishi et al., 1998), while in inland areas along the traverse route between Syowa Station and Dome Fuji, it is about 30 mm (Motoyama et al., 2015). If half of the annual precipitation is attributed to clear-sky precipitation and it occurs over 180 days (i.e., half of the year), then the daily precipitation rate would be 0.56 mm/day (0.02 mm/hr) at Syowa Station and 0.08 mm/day (0.003 mm/hr) in inland areas. These values indicate that the resolution of Geonor T200B is insufficient for measuring clear-sky precipitation on an hourly basis.

Lidars and laser disdrometers can detect very weak precipitation. Gorodetskaya et al. (2015) showed that a ceilometer detected very weak snowfall or ice cloud layer below 1000 m from ground surface at Princess Elisabeth Station in coastal Antarctica. But converting these measurements into precipitation amounts presents challenges. Lolli et al. (2018) examined methods for estimating precipitation intensity for very weak rainfall (<3 mm/hr) using micropulse lidar and disdrometer observations. Rocadenbosch et al. (2020) proposed a method to estimate precipitation intensity from backscatter measurements obtained using a Vaisala CL31 ceilometer during rain events with intensities below approximately 10 mm/hr. The backscattering intensity of the laser is influenced not only by the quantity of particles, but also by the shape of the ice crystals and the orientation of their faces when the scatterers are ice particles. Consequently, efforts to estimate precipitation intensity from laser backscatter intensity have focused primarily on rainfall. An effort targeting ice particles involved the development of an algorithm to detect the presence or absence of blowing snow using a ceilometer (Gossart et al., 2017).

Based on the Clausius-Clapeyron equation, global warming is expected to promote an increase in water vapor, leading to an increase in precipitation. Trenberth *et al.* (2003) estimated that the rate of increase in atmospheric water vapor capacity is approximately 7% K^{-1}, which implies that the overall rate of the increase in precipitation should follow the same trend. In the latest Intergovernmental Panel on Climate Change (IPCC) special report (Meredith et al. 2019; The Ice sheet Mass Balance Inter-comparison Exercise (IMBIE) Team 2018), it is projected that Antarctic precipitation will increase as warming progresses.

This increase in precipitation is attributed to both relatively intense precipitation events associated with synoptic disturbances, which can be measured by radar (Hirasawa *et al.* 2022), and extremely weak precipitation, such as clear-sky precipitation. Accurately quantifying the amount and intensity of weak precipitation, including clear-sky precipitation, remains challenging when using lidars, ceilometers, and laser disdrometers. However, these instruments can, to some extent, detect the presence or absence of weak precipitation. Detecting and recording the intensity and duration of weak precipitation in Antarctica would be valuable, as such records serve as indicators of global warming and could be used effectively in future studies.

In this study, we investigated the effectiveness of a ceilometer and a laser disdrometer for detecting extremely weak precipitation and compared these findings to measurements obtained using conventional precipitation measurement methods. The data for the analysis were obtained in Rikubetsu, one of the coldest regions in Japan (Sorai *et al.*, 2016), where clear-sky precipitation is occasionally observed.

2. Observations and analysis

2.1 Observation site and instruments

Snowfall and meteorological measurements have been conducted at an observation site in Rikubetsu (43.5°N, 143.8°E, 217 m above sea level) since 2012 (Fig. 1a). Rikubetsu is located on the eastern side of the central mountain range in Hokkaido (indicated by the white dashed line in Fig. 1a). During heavy snowfall events on the Sea of Japan side of Hokkaido caused by the Asian winter monsoon, most of the areas on the Pacific Ocean side, including Rikubetsu, generally experience clear skies. Snowfall in Rikubetsu is typically associated with frontal activity driven by synoptic-scale disturbances passing through the region (*e.g.*, Kawase *et al.*, 2023, Hirasawa and Konishi, 2024). The daily winter minimum air temperature occasionally drops below -30°C. This cold environment makes Rikubetsu a valuable test site for conducting snowfall observations relevant to Arctic and Antarctic conditions.

The specifications of the instruments used in this study are summarized in Table 1, and the location of each instrument is shown in Fig. 1b. The backscatter coefficients measured by the ceilometer (Fig. 1c) and the particle counts recorded by the disdrometer (Fig. 1d) allowed the detection of extremely weak precipitation events that were not captured by the two weighing gauges installed at the site. The disdrometer was placed at the center of a wooden double-fence enclosure designed for wind protection.

One of the weighing gauges (Fig. 1e), manufactured by Geonor Inc. (Norway), is an internationally recognized standard instrument. It was positioned at the center of another wooden double fence. During SPICE, data from this Geonor weighing gauge data were used for intercomparison among observation sites as part of the Double Fence Intercomparison Reference (DFIR). The second weighing gauge was custom-built, consisting of a bucket and an electronic scale (Fig. 2a). It was designed to achieve higher sensitivity than the Geonor weighing gauge, making it suitable for detecting relatively weak precipitation events. However, it was less reliable for measuring precipitation amounts due to sublimation from the snow surface in the bucket and the relatively low catchment rate of snow particles. This latter limitation was attributable to a simple windshield constructed from plastic nets.

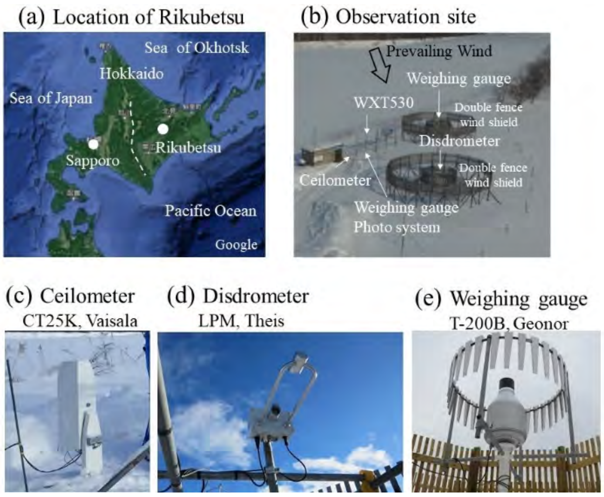

Fig. 1 (a) Map of Hokkaido showing Rikubetsu and topography of the region; (b) Landscape surrounding the observation site; (c) Ceilometer; (d) Disdrometer in the double fence windshield; and (e) Weighing gauge in the double fence windshield.

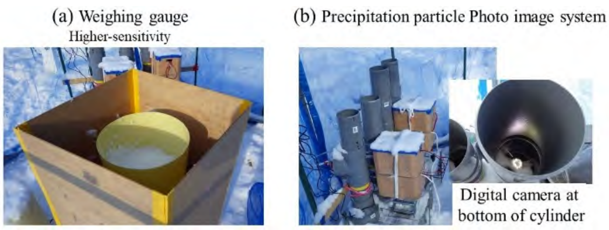

Fig. 2 (a) Weighing gauge with higher-sensitivity; (b) Precipitation particle imaging system.

An automatic photography system was installed (Fig. 2b). The system consisted of a digital camera positioned in the lower part of a plastic cylinder. The camera captured images of the surface of a plastic plate from below at one-minute intervals.

Table 1 Specifications of instruments for precipitation measurements

Instrument, Model name, Manufacturer, Country
Description
Ceilometer, CT25K, Visala, Finland
Backscatter coefficient of a laser with a wave length of 905 nm
Every 30 m layer from the ground level to a height of 7500 m
Data interval: 15 seconds
Observation period: December 1, 2014 - March 31, 2015
Disdrometer, LPM, Thies Clima, Germany
Number of particles per minute by particle size and fall velocity
Small particle size classification: 0-125 μm, 125-250, 250-375, 375-500, 500-750, 750-1000
Precipitation intensity (mm/hr) determined from laser attenuation
Data interval: 1 minute
Observation period: December 1, 2014 - March 31, 2015
Weighing gauge, T-200B, Geonor Inc., Norway
Cumulative precipitation (mm)
Resolution: 0.02-0.05 mm, depending on the weight
Data interval: 1 minute
Observation period: December 1, 2014 - March 31, 2015
Weighing gauge, Custom-built for higher sensitivity measurement
Cumulative precipitation (mm)
Resolution: 0.001 mm (bucket diameter: 365 mm, weight resolution: 0.1 g)
Data interval: 15 seconds
Observation period: December 23, 2014 - February 14, 2015
Precipitation particle photography, Custom-built
Digital image
Data interval: 1 minute with cleaning up by air splayed
Observation period: December 22, 2014 - January 1, 2015, January 11 - 15, 2015
Surface Meteorology-1, WXT530, Vaisala, Finland
Temperature, wind speed and direction, relative humidity, pressure
Data interval: 15 seconds
Observation period: December 1, 2014 - January 1, 2015, January 16 - 24, 2015, February 1 - 7, 2015, February 19 - March 31, 2015
Surface Meteorology-2, Custom-built in conjunction with manufacturers
Temperature (Platinum Resistance), relative humidity (HMP45D, Vaisala, Finland)
Data interval: 1 hour
Observation period: December 1, 2014 - March 31, 2015

Surface meteorological observations were conducted using two sets of instrumentation. Surface Meteorology-1 (Table 1) was installed near the snowfall instruments (Fig. 1b). However, due to frequent data gaps, measurements from Surface Meteorology-2 (Table 2), located approximately 50 m away, were also used in the analysis. To address differences in air temperature and relative humidity measured by the two instruments, the data from Surface Meteorology-2 were corrected to match those from instrument 1. Let T1, RH1, T2, RH2, T2c, and RH2c represent the air temperature and relative humidity recorded by instrument 1, instrument 2, and after correction, respectively. The following correction equations, obtained through linear regression, were applied: $T_{2c} = 0.9778\ T_2 + 0.9568$, $RH_{2c} = 0.7401\ RH_2 + 16.606$.

2.2 Analysis

The ceilometer recorded backscatter coefficients at intervals of 30 m from the ground level to a height of 7500 m. For this study, backscatter coefficients from the first and second lowermost layers, corresponding to altitudes of 0–30 m and 30–60 m, were analyzed. It should be noted that the lowermost layer may be contaminated by snow particles lofted from the ground surface under the strong wind conditions, and we need to handle this possibility with that in mind, and this possibility was considered during the analysis.

The disdrometer measured precipitation intensity based on laser attenuation and recorded the size distribution of precipitation particles. Particle size (diameter) was classified into the following size ranges: 0–125 μm, 125–250 μm, 250–375 μm, 375–500 μm, 500–750 μm, 750–1000 μm, and larger size classes. Due to frequent errors of unknown origin in the smallest class (Hirasawa et al. 2018), data from this size class were excluded from the analysis.

During extremely weak precipitation events, the disdrometer often recorded a precipitation intensity of 0 mm/hr while detecting particles within the smaller diameter range. Therefore, we analyzed the number of particles with diameters between 125 and 1000 μm as evidence for the occurrence of extremely weak precipitation.

The Geonor weighing gauge, with a resolution of approximately 0.04 mm, was also used. However, it has been reported that its measurements are subject to drift caused by diurnal variations in temperature (Hirasawa et al., 2018). For example, a temperature change of 20°C can result in a change as large as 5 mm, which is equivalent to 10 times the instrument's resolution.

In the remainder of the paper, we first examine whether precipitation events weaker than the detection threshold of the Geonor weighing gauge can be detected by other instruments. Next, we identify the most effective measurements for detecting extremely weak precipitation events. Finally, we discuss the possible formation mechanism of these extremely weak precipitation events.

3. Results

3.1 Detection of precipitation events

Figure 3 shows the time series of precipitation intensity (mm/10 min) and cumulative precipitation (mm) measured by three instruments. The Geonor weighing gauge (Fig. 3a) exhibits diurnal variations with an amplitude of approximately ±0.05 mm/10 min, caused by temperature-dependent drift in the measured values. These diurnal variations are compensated for in the cumulative precipitation data. Values greater than +0.05 mm, as detected by the Geonor weighing gauge, are considered precipitation events and are shaded red in all panels of Fig. 3.

The higher-sensitivity weighing gauge (Fig. 3b) detected precipitation events weaker than 0.05 mm/10 min outside the red-shaded periods. Unlike the Geonor weighing gauge, this weighing gauge did not suppress sublimation from the snow surface, which primarily resulted in negative precipitation intensity during the daytime. The cumulative precipitation shown here represents the cumulative precipitation minus sublimation, reflecting the water balance at the snow cover surface. It is important to note that this measurement may underestimate or fail to detect precipitation when sublimation and precipitation occur simultaneously during the daytime. The comparison of precipitation intensity between the higher-sensitivity weighing gauge and the Geonor weighing gauge (Fig. 4a) may reflect this underestimation. Precipitation events outside the red-shaded periods in Figure 3 correspond to the datapoints plotted to the left of the red vertical line in Figure 4.

The disdrometer (Fig. 3c) also detected precipitation events weaker than 0.05 mm/10 min, with their timing closely matching that of the higher-sensitivity weighing gauge. The cumulative precipitation measured by the disdrometer was the largest among the three instruments. This is likely because, unlike the higher-sensitivity weighing gauge, the disdrometer is not affected by snow sublimation. However, further validation of precipitation intensity estimates based on laser attenuation should be conducted in the future. As shown in Fig. 4b, the disdrometer tended to overestimate precipitation intensity compared to the Geonor weighing gauge more frequently than the higher-sensitivity weighing gauge. However, verification of the quantitative accuracy of these measurements lies outside the scope of this study.

3.2 Extremely weak precipitation events

Figure 4 shows that in almost all cases where the Geonor weighing gauge detected precipitation, the disdrometer also detected precipitation (Fig. 4b). Conversely, there are several instances where precipitation detected by the Geonor weighing gauge was not detected by the higher-sensitivity weighing gauge (circled in Fig. 4a), likely due to sublimation. Therefore, this study defines the very weak precipitation events that were detected by the laser attenuation method of the disdrometer, that is, more than 0 mm/10 min, during periods when the Geonor weighing gauge did not detect precipitation as Extremely Weak Precipitation of Type-I (EWP-I) events.

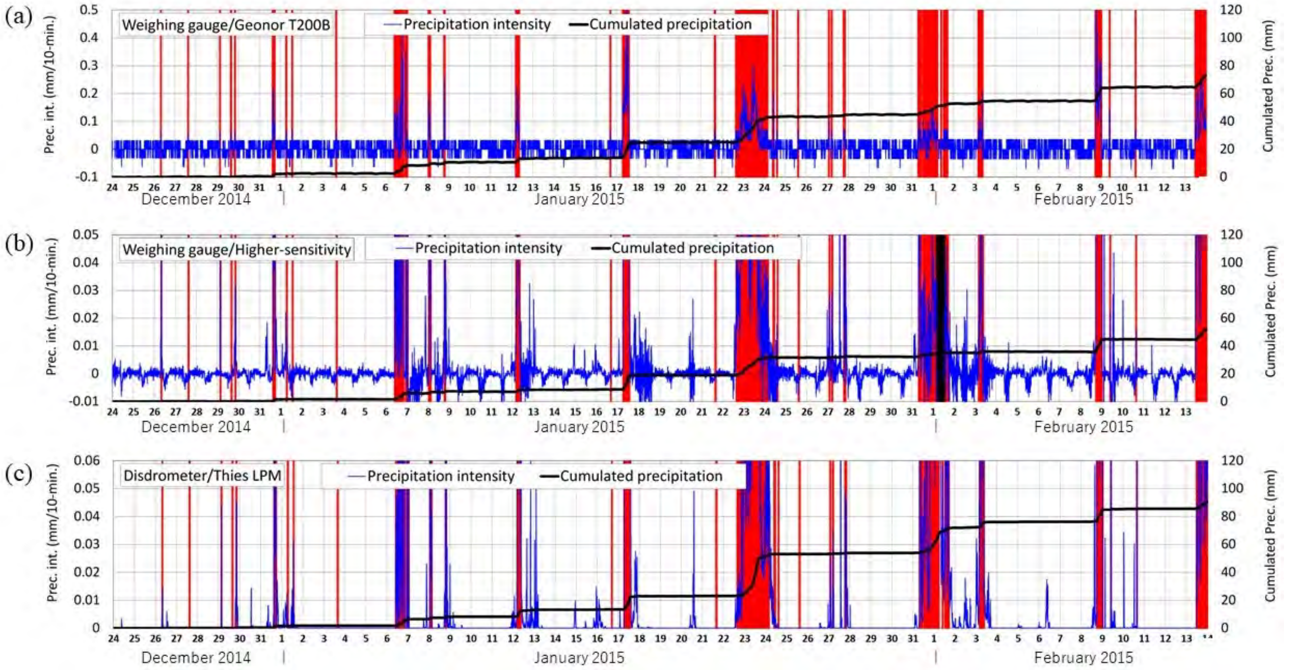

Fig. 3 Time series of precipitation intensity (mm/10 min) and cumulative precipitation (mm) from December 24, 2014 to February 13, 2015 for (a) the Geonor weighing gauge, (b) the higher-sensitivity weighing gauge (with approximately eight hours of data missing on February 1, indicated by black shading), and (c) the disdrometer. Periods when the Geonor weighing gauge detected precipitation exceeding 0.05 mm in 10 minutes are indicated by red shading.

Figure 5 shows a time series of particle counts per minute for particles with diameters ranging from 125 to 1000 µm, measured over 10-minute intervals by the disdrometer, alongside the averaged backscatter coefficients for the two lowermost layers measured over 10-minute intervals by the ceilometer. Periods identified as EWP-I are shaded in green.

The disdrometer recorded particle counts even outside the EWP-I periods. Particles in the smaller size range of 125 to 1000 µm were detected primarily during the nighttime. This diurnal variability was not identified in the study by Hirasawa and Konishi (2023), which analyzed diurnal variability at this station, including the period of this study, because their analysis excluded precipitation that occurred outside the EWP-I periods.

Variability in the backscatter coefficients for the lowermost layer (0–30 m in height) measured by the ceilometer correlates with the particle counts recorded by the disdrometer. In certain cases, indicated by the bold downward-pointing arrow in Fig. 5a), precipitation particles were captured in photographs, as shown in Fig. 6. This suggests that the observed variability in particle counts and backscatter coefficients likely reflects actual precipitation. Diurnal variability is also evident in the second lowermost layer of the ceilometer but is notably suppressed overall, e.g., on December 28 and January 4–5. This suppression in the upper layer may be related to the mechanism of precipitation particle formation, which will be discussed in the following section.

This paper defines the extremely weak precipitation detected based on the particle counts of the disdrometer or the backscatter intensity of the ceilometer, occurring outside the EWP-I periods, as Extremely Weak Precipitation of Type-II (EWP-II).

4. Discussion

4.1 Temporal occurrence of extremely weak precipitation

Table 2 summarizes the temporal occurrence of each type of precipitation event. The analysis period consisted of 7498 ten-minute intervals, during which the Geonor weighing gauge detected precipitation in 469 intervals. This represents the normally observed precipitation, indicating an overall precipitation incidence of 6.3% during this study period.

EWP-I was detected in 1493 of the remaining 7020 10-minute intervals, excluding periods when the Geonor weighing gauge detected precipitation. This corresponds to 20% of the total time. Similarly, EWP-II detected by either instrument occurred in 1802 of the remaining 5527 ten-minute intervals, accounting for approximately one-third of the time. This significant temporal occurrence of EWP-II is comparable to clear-sky precipitation in Antarctica.

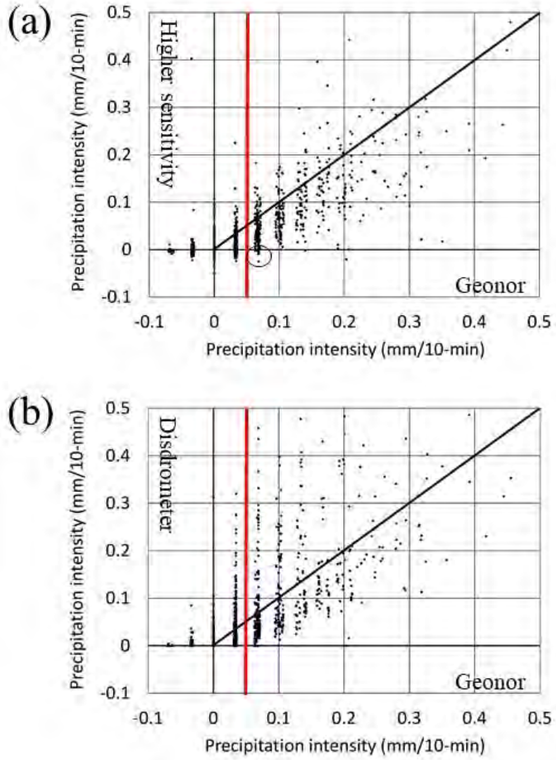

Fig. 4 Comparison of measured precipitation intensity between instruments. (a) Geonor weighing gauge vs. higher-sensitivity weighing gauge; (b) Geonor weighing gauge vs. disdrometer. Precipitation events detected by the Geonor weighing gauge are plotted to the right of the red vertical line (0.05 mm/10 min). The circle in (a) indicates the reference area discussed in the text.

4.2 Diurnal variability of EWP-II

Figure 7 shows the time dependence of the EWP-II. Precipitation particles in the smallest diameter range were frequently detected between 21:00 and 6:00 JST. During this period, stronger backscatter intensity ($\geq 5 \times 10^{-7}$ sr^{-1} m^{-1}) was detected by the ceilometer more frequently than at other times of the day. This paper refers to this backscatter intensity as an indicator of precipitation particles.

The contrast between nighttime and daytime for EWP-II is more pronounced for particle detection data from the disdrometer than in the ceilometer backscatter intensity (Fig. 7b). Specifically, from December 24 to January 5, nighttime particle detection by the disdrometer exceeded the mean value by a factor of two, while it decreased to a factor of 0.2 during the daytime. The ceilometer backscatter intensity also exhibited a distinct nighttime-to-daytime contrast during the same period. Notably, the increase in backscatter intensity toward nighttime began around 18:00, earlier than the rise in particle counts detected by the disdrometer.

The contrast between nighttime and daytime backscatter intensities was considerably weaker during the analyzed period. One possible explanation for this is that the backscatter intensity of the ceilometer is affected by changes in the amount of scatterers other than precipitation particles. This factor should be considered when detecting EWP-II using the backscatter intensity of the ceilometer.

4.3 Mechanism of the EWP-II formation at night

Figure 8 compares the time series of backscatter intensity and particle counts with surface air temperature and relative humidity (with respect to ice) from December 24, 2014, to January 5, 2015. Surface temperatures ranged between -5°C during the daytime and -25 to -30°C at night. Relative humidity exceeded 100% at around 17:00 to 18:00 when the temperature was dropping, and it remained below 100% by approximately 9:00 when the temperature increased markedly. The occurrence of EWP-II, indicated by increases in both backscatter intensity and particle detection, appears to be related to the development of low-temperature and high-humidity conditions at night. Relative humidity with respect to ice often remained below 100%, suggesting that the precipitation particles that formed during this period were ice crystals, commonly referred to as diamond dust.

The mechanism responsible for the formation of EWP-II, as well as the differences in variation between ceilometer backscatter intensity and disdrometer particle detection, are analyzed using altitude-time cross-sections of the ceilometer backscatter coefficient (Fig. 9) and detailed time series of temperature and relative humidity (Fig. 10).

Figure 9 shows precipitation from the upper atmospheric levels on December 26, from 7:00 to 14:00, and on December 29, from 3:00 to 4:00 and after 18:00. During these periods, EWP-I and EWP-II co-occurred (Fig. 5). In contrast, from the evening of December 26 to the morning of December 28, EWP-II events did not originate as precipitation from upper atmospheric levels. On both nights, the atmosphere became ice-saturated before 18:00 and remained so until after 8:00 the following morning. The disdrometer detected precipitation particles only under these ice-saturated conditions, while water saturation was not reached during either night (data not shown). These observations suggest that the EWP-II events during these nights were likely associated with the deposition of ice crystals, which subsequently fell.

Conversely, the backscatter intensity of the ceilometer increased at approximately 15:00 before the onset of ice saturation. This timing closely followed the decrease in temperature from the daytime maximum and likely reflected the growth of hygroscopic aerosols. These observations suggest that EWP-II was composed of supercooled water droplets, at least during the starting phase.

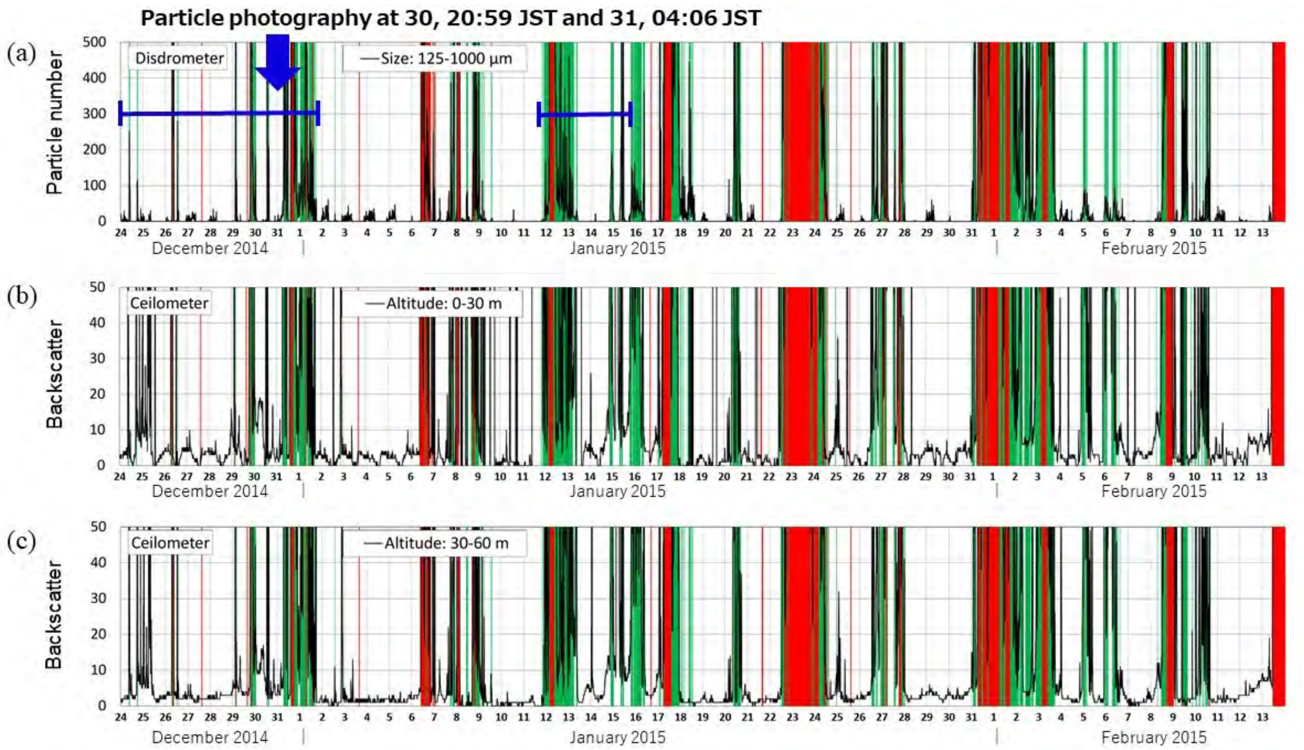

Fig. 5 Time series of precipitation-related measurements. (a) Averaged number of particles (per minute) with diameters ranging from 125 to 1000 μm, measured over 10-minute intervals by the disdrometer, and (b, c) averaged backscatter coefficients of the atmospheric layers at heights of 0–30 m and 30–60 m, respectively, measured over 10-minute intervals by the ceilometer. Periods of EWP-I are shaded in green. In (a), blue lines with whiskers indicate the periods during which precipitation particle photography was conducted. The blue arrow marks the timing of the precipitation photographs shown in Fig. 6.

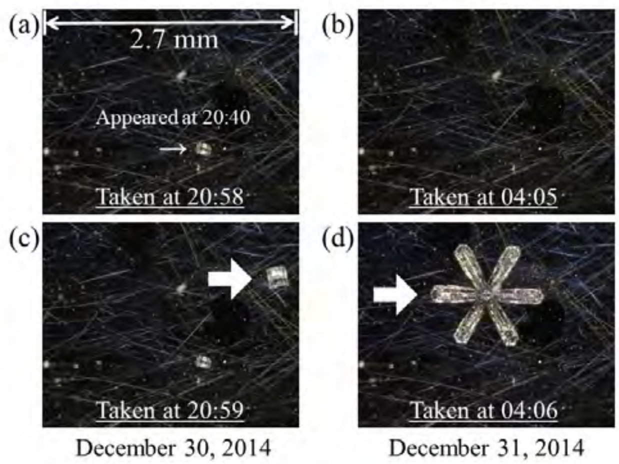

Fig. 6 Sequential precipitation particle photographs taken during EWP-II. Photographs captured at (a) 20:58 (JST) and (c) 20:59 on December 30, 2024, and at (b) 04:05 and (d) 04:06 on December 31, 2024. Bold arrows indicate particles that appeared within the 1-minute interval. The smaller arrow indicates a particle that appeared previously, with the corresponding time. The horizontal width of each photograph is 2.7 mm.

Table 2 Temporal occurrence of each type of precipitation

Instruments, Data Items	Precipitation	Extremely weak precipitation of Type-I	Extremely weak precipitation of Type-II
	Time Detected / Total Eligible Time (10-minute intervals) Percentage (%)		
Geonor weighing gauge	469 / 7489 6.3%	-	-
Disdrometer (attenuation)	-	1493 / 7020 21.3%	-
Disdrometer (particle counts) 125 μm - 1 mm	-	-	1730(*) / 5527 31.3%
Ceilometer (backscatter) (≥5 x 10^{-7} sr^{-1} m^{-1}) Layer 0-30 m in height	-	-	1802(*) / 5527 32.6%

*Note: 855 times were synchronized

However, in all cases, the EWP-II observed during the two nights could have been formed by radiative cooling of the ground surface. While the disdrometer only detects particles larger than 125 μm, the ceilometer may have observed backscattering from smaller particles, suggesting that the ceilometer backscatter intensity could potentially be a more effective method for detecting extremely weak precipitation in colder polar regions.

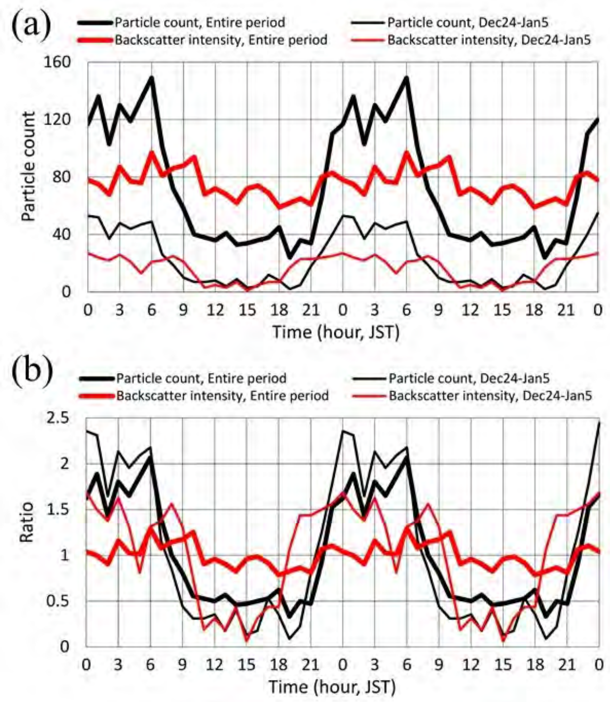

Fig. 7 Time dependence of EWP-II. (a) Black lines represent the 10-minute counts during which the disdrometer detected particles, while the red lines represent the 10-minute counts during which the ceilometer backscatter intensity was ≥ 5 × 10^{-7} sr^{-1} m^{-1} in the 0–30 m layer. Thick lines indicate the entire analyzed period, while thin lines represent data from December 24 to January 5, when the diurnal variation is clearly characterized. The 24-hour cycle is shown repeated twice. (b) Same as (a), but showing the ratio to the mean.

The promotion of particle formation and growth may be weaker in the second lowermost layer, from 30 m to 60 m in height, than in the first layer because of the smaller temperature drop induced by radiative cooling of the ground surface. In addition, particles fall out into the first layer. These processes cause the variation in ceilometer backscatter to be less in the second layer than in the first layer.

From the evening of December 28 to the morning of December 29, the minimum temperature appeared around 0:00 on December 29, which differs from the pattern observed on the previous two nights. Ice saturation was only observed briefly, before and after the minimum temperature occurred. The backscatter intensity recorded by the ceilometer began to increase after the daytime maximum temperature and reached higher values at around 0:00, which coincided with the minimum temperature. Unlike the preceding two nights, this increase in backscatter at midnight was associated with precipitation from upper clouds. The disdrometer detected precipitation particles only once, at 0:10. These observations suggest that the ceilometer is better suited for detecting extremely weak precipitation, particularly of small particles, than the disdrometer. Precipitation detected solely by the ceilometer may be classified as Extremely Weak Precipitation of Type-III (EWP-III).

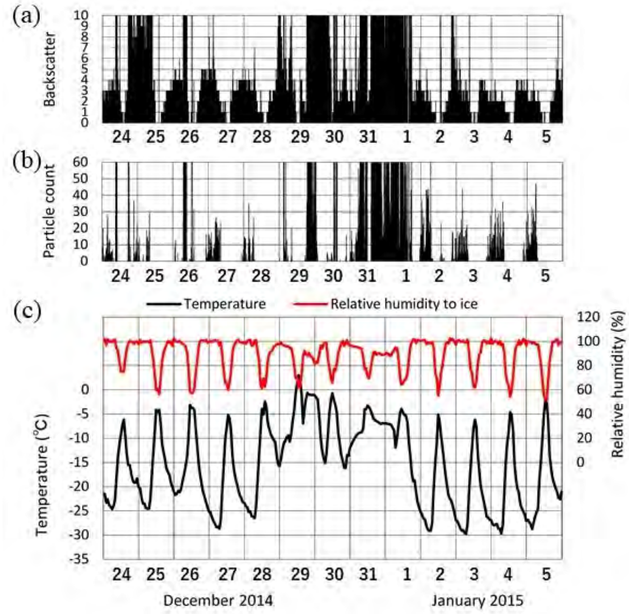

Fig. 8 Time series data. (a) Backscatter intensity (10^{-7} sr^{-1} m^{-1}) in the 0–30 m layer, (b) particle counts for diameters ranging from 125 to 1000 μm in diameter, and (c) temperature and relative humidity with respect to ice, as observed by the Surface Meteorology-2, from December 24, 2014, to January 5, 2015.

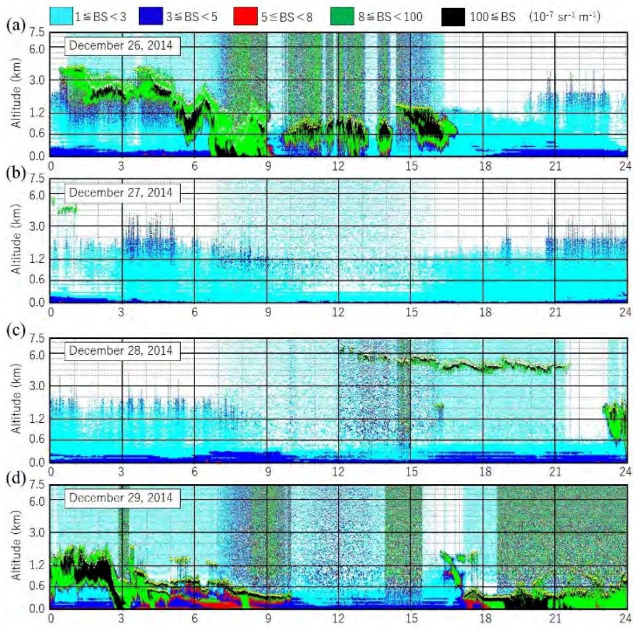

Fig. 9 Altitude-time cross-section of backscatter coefficient measured by the ceilometer from December 24 to 29, 2014.

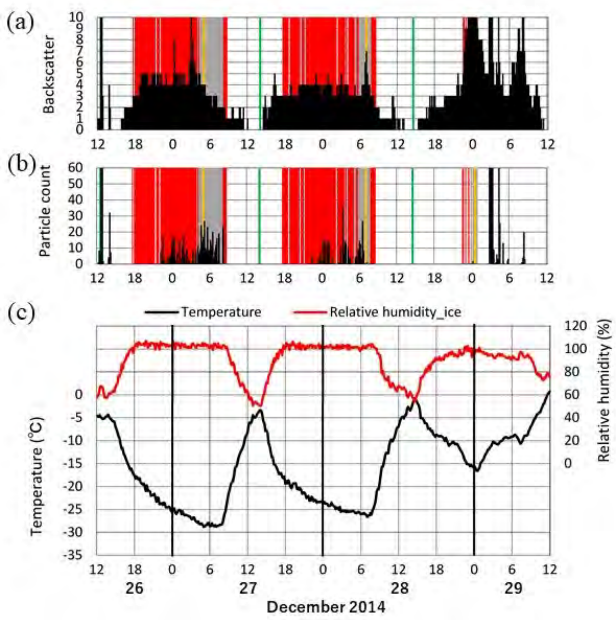

Fig. 10 Same as Fig. 8, but with observations from Surface Meteorology-1 from 12:00, December 26 to 12:00, December 28, 2014. In (a) and (b), red shading indicates periods of ice saturation, while gray shades mark times within 1°C of the nighttime minimum temperature (vertical orange line). The vertical green line represents the time of the daytime maximum temperature.

The precipitation particles detected by the disdrometer in non-ice-saturated conditions on the morning of December 29 are presumed to have originated from upper clouds.

5. Conclusion

Measuring extremely weak precipitation in polar regions is crucial due to the low temperatures and corresponding low humidity in these areas. Understanding the contribution of such precipitation, including clear-sky precipitation, to the ice mass balance of the Antarctic ice sheet is essential for understanding the mechanisms of ice sheet mass change related to global warming and for improving future projections using climate models. However, no established method currently exists for measuring such weak precipitation in polar regions. This study examined how ceilometers, disdrometers, and precipitation weighing instruments detect weak precipitation in Rikubetsu (43.5°N, 143.8°E), inland Hokkaido. The findings showed that the disdrometer and ceilometer detected weak precipitation that was not recorded below the detection thresholds of precipitation weighing measurements. Weak precipitation was classified into Extremely Weak Precipitation of Type-I (EWP-I), characterized by relatively high precipitation intensity, and Extremely Weak Precipitation of Type-II (EWP-II), characterized by lower intensity. EWP-II was detected by the disdrometer, which detects precipitation particles, and by the ceilometer, which measures backscatter intensity. During EWP-II events, actual precipitation particles were photographed. EWP-II occurred mainly at night, where the increase in relative humidity caused by surface air temperature drops due to radiative cooling was a key factor. The disdrometer detected precipitation particles only under ice-saturated conditions, while the ceilometer recorded increases in backscatter relatively soon after temperatures began to decline following daytime maximums. Since the disdrometer could not detect particles smaller than 125 μm, the ceilometer likely captured the effects of smaller particles. Precipitation detected only by the ceilometer is classified as Extremely Weak Precipitation of Type-III (EWP-III). The identification of EWP-II and EWP-III highlights the potential of using ceilometers and disdrometers to record extremely weak precipitation, including clear-sky precipitation, in polar regions.

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Summary in Japanese

和文要約

北海道内陸部の陸別における極端に弱い降雪の検出

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極域の大気は低温のために、そこに含まれる水蒸気量は少なく、それに応じて降水強度が比較的弱い。例えば南極内陸では晴天降水が年間の半分以上の時間を占めることから、南極氷床の涵養にとって晴天降水の寄与の大きさが想像されてきた。しかしながら、我々は極域におけるこのような極端に微弱な降水量を計測する方法を構築できていない。論文は陸別町におけるシーロメター、ディスドロメター、重量式降水量計測が微弱な降水をどのように検出するのかを調べた。降水重量計測が降水を検出しなかった期間に、ディスドロメター―やシーロメターが微弱な降水を検出することが分かった。本研究は、このような微弱な降水を比較的降水強度の強いタイプ I の極端微弱降水（EWP-I）と強度のより弱いタイプ II の極端微弱降水（EWP-II）とに分けた。EWP-II は、ディスドロメターよる降水粒子の検出及びシーロメター―による後方散乱強度の増加によって検知され、実際に降水粒子が撮影された。EWP-II は主に夜間に観測され、そこでは放射冷却にともなう地上気温の低下が引き起こす相対湿度の上昇が重要である。ディスドロメター―は氷飽和の条件下でのみ降水粒子を検出し、シーロメター―は昼間に最高気温を記録した後の気温低下は始まった比較的直ぐに後方散乱の増加を観測した。ディスドロメターは粒径が 125 μm 以下の粒子を検出しないことから、シーロメター―はより小さな粒子の影響を捉えた可能性がある。このような更に弱い降水を EWP-III として分類できる。EWP-II と EWP-III の検出は、極域における晴天降水を含む極めて弱い降水の、少なくとも発生を記録することができることを示している。

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